IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

POLAROID CORPORATION, Plaintiff and Counterclaim Defendant, v. HEWLETT-PACKARD COMPANY, Defendants and Counterclaim Plaintiff.	C.A. No. 06-738-SLR REDACTED

**DECLARATION OF WILLIAM J. MARSDEN, JR.
IN SUPPORT OF DEFENDANT HEWLETT-PACKARD'S
OPENING CLAIM CONSTRUCTION BRIEF**

FISH & RICHARDSON P.C.
William J. Marsden, Jr. (#2247)
919 N. Market Street, Suite 1100
Wilmington, DE 19801
Telephone: (302) 652-5070

John E. Giust
Matthew E. Bernstein
12390 El Camino Real
San Diego, CA 92130
Telephone: (858) 678-5070

Bradley D. Coburn
111 Congress Avenue, Suite 810
Austin, TX 78701
Telephone: (512) 472-5070

CHOATE, HALL & STEWART
Daniel C. Winston
Two International Place
Boston, MA 02110
Telephone: (617) 248-5000

Attorneys for Defendant and Counterclaim-Plaintiff Hewlett-Packard Company

Dated: January 11, 2008

I, William J. Marsden, Jr., declare as follows:

1. I am an attorney with Fish & Richardson P.C., counsel for Plaintiff Power Integrations, Inc. I am a member of the Bar of the State of Delaware and of this Court. I have personal knowledge of the matters stated in this declaration and would testify truthfully to them if called upon to do so.

2. Attached hereto as Exhibit A is a true and correct copy of excerpts from Azriel Rosenfeld and Avinash C. Kak, Digital Picture Processing, (1st ed. 1976).

3. Attached hereto as Exhibit B is a true and correct copy of Computer Graphics Systems Development, Gamma Correction Explained, http://www.siggraph.org/education/materials/HyperGraph/color/gamma_correction/gamma_intro.html (downloaded January 10, 2008).

4. Attached hereto as Exhibit C is a true and correct copy of excerpts from the transcript to the Deposition of Donald S. Levinstone (September 26, 2007).

5. Attached hereto as Exhibit D is a true and correct copy of U.S. Patent No. 4,394,688 (filed August 25, 1981).

6. Attached hereto as Exhibit E is a true and correct copy of excerpts from The Oxford English Dictionary, Vol. 3 (J.A. Simpson and E.S.C. Weiner, eds., 1989).

7. Attached hereto as Exhibit F is a true and correct copy of excerpts from Margaret L. Lial and John Hornsby, Intermediate Algebra (8th ed. 2000).

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Executed this 11th of January, 2008 at Wilmington, Delaware.

/s/ William J. Marsden, Jr.
William J. Marsden, Jr.

CERTIFICATE OF SERVICE

I hereby certify that on January 18, 2008, I electronically filed with the Clerk of Court the foregoing **REDACTED DECLARATION OF WILLIAM J. MARSDEN, JR. IN SUPPORT OF DEFENDANT HEWLETT-PACKARD'S OPENING CLAIM CONSTRUCTION BRIEF** using CM/ECF which will send electronic notification of such filing(s) to the following counsel:

Jack B. Blumenfeld (#1014)
Julie Heaney (#3052)
Morris, Nichols, Arsht & Tunnell, LLP
1201 North Market Street
Wilmington, DE 19899-1347
Phone: 302-658-9200
Fax: 302-658-3989
Emails: jblumenfeld@mnat.com; jheaney@mnat.com

Attorneys for Plaintiff and
Counterclaim-Defendant
Polaroid Corporation

In addition, service will be made on the following counsel of record as indicated:

Via Electronic Mail
Russell E. Levine, P.C./C. Graham Gerst
Michelle W. Skinner/David W. Higer
Maria A. Meginnes/Courtney Holohan/C. Beasley
Kirkland & Ellis LLP
200 East Randolph Drive
Chicago, IL 60601
Phone: 312-861-2000
Fax: 312-861-2200
Emails: rlevine@kirkland.com;
ggerst@kirkland.com; skinnerm@kirkland.com;
dhiger@kirkland.com; mmeginnes@kirkland.com;
cholohan@kirkland.com; cbeasley@kirkland.com

Attorneys for Plaintiff and
Counterclaim-Defendant
Polaroid Corporation

Courtesy Copy Via Overnight Mail
Michelle W. Jordan
Kirkland & Ellis LLP
200 East Randolph Drive
Chicago, IL 60601
Phone: 312-861-2000
Fax: 312-861-2200

/s/ William J. Marsden, Jr.
William J. Marsden, Jr. (#2247)

Exhibit A

DIGITAL PICTURE PROCESSING

Rosenfeld
Kak

ACADEMIC PRESS

Computer Science
and Applied Mathematics

DIGITAL PICTURE PROCESSING

Azriel Rosenfeld and Avinash C. Kak

Digital Picture Processing

Digital Picture Processing

AZRIEL ROSENFELD

Computer Science Center
University of Maryland
College Park, Maryland

AVINASH C. KAK

School of Electrical Engineering
Purdue University
West Lafayette, Indiana

This is a volume in
COMPUTER SCIENCE AND APPLIED MATHEMATICS
A Series of Monographs and Textbooks

Editor: WERNER RHEINBOLDT

A complete list of titles in this series appears at the end of this volume.

ACADEMIC PRESS New York San Francisco London 1976
A Subsidiary of Harcourt Brace Jovanovich, Publishers

considers nongeometrical picture properties (e.g., texture) and the description of pictures in terms of parts, properties, and relationships.

In the remainder of this chapter, we discuss the relationship between continuous and discrete pictures, and the representation of (discrete) pictures in a digital computer. We also give a brief guide to the picture-processing literature. In the next chapter, we review various useful mathematical tools.

1.2 PICTURES AND THEIR COMPUTER REPRESENTATION

1.2.1 Pictures as Functions

Informally, a *picture* is a flat object whose brightness or color may vary from point to point. This variation can be represented mathematically by a function of two spatial variables. When color is involved, the function should be regarded as vector valued, or several functions should be used; see Section 3.3. In this book, however, we will be dealing almost exclusively with black-and-white pictures in which there can be shades of gray, but no color. Such a picture can be represented by a single real-valued function, say $f(x, y)$. The value of this function at a point will be called the *gray level* or *brightness* of the picture at that point.

It is customary to assume that the functions that represent pictures are analytically well behaved—so that, for example, these functions are integrable, have invertible Fourier transforms, etc. It is usual also to regard these functions as having values that are nonnegative and bounded, i.e., $0 \leqslant f(x, y) \leqslant M$ for all x, y.

1.2.2 Pictures as Arrays

When a picture is *digitized* (Chapter 4), a *sampling* process is used to extract from the picture a discrete set of real numbers ("samples"), and a *quantization* process is applied to these samples to yield numbers having a discrete set of possible values. In most practical situations, the samples are the values of the picture at a discrete, usually regularly spaced, set of points—or, more realistically, averages of the values taken over small neighborhoods of such points. Such a set of samples can be represented, for computer-processing purposes, as a (rectangular) *array* of real numbers. The samples are usually quantized to a set of equally spaced gray level values (see Section 4.3). If the unit of measurement is suitably chosen, these values can be taken to be integers; thus a digitized picture, or *digital picture*, can be regarded as an

integer array.† The elements of a digital picture array are called *picture elements*, *pixels*, or *pels*, or sometimes just "points."

The most common method of picture sampling is to use a regularly spaced *square* array of points, i.e., points (md, nd) whose coordinates are multiples of some unit distance d. In such an array, every point has two kinds of neighbors—four horizontal and vertical neighbors (above, below, to the left, and to the right), at distance d from the point, and four diagonal neighbors at distance $d\sqrt{2}$. (Some of the complications introduced by the existence of these two types of neighbors will be discussed in Chapter 9.) Of course, at the edges of the array, some of these neighbors will not exist.

Another possibility is to use a regular *hexagonal* array of sample points; here each point has six neighbors, all at the same distance from it. One can obtain a similar kind of neighborhood from a square array by shifting, say, odd-numbered rows $d/2$ to the right (see Fig. 1). In fact, rather than do the

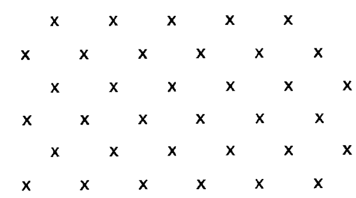


Fig. 1 "Hexagonal" array obtained by shifting odd-numbered rows of a square array.

actual shifting, one can simply stipulate that, for a point p on an odd-numbered row, the neighbors of p are its four horizontal and vertical neighbors together with just *two* of its diagonal neighbors, namely those to the northeast and southeast; and similarly for p on an even-numbered row, but this time allowing only the northwest and southwest diagonal neighbors.

The picture arrays that are processed in practice can be very large. For example, suppose that we want to sample and quantize an ordinary television image finely enough so that it can be redisplayed without noticeable degradation. Then we should use an array of about 500 × 500 samples, and we should quantize the samples to at least 30–50 discrete gray levels, i.e., a quarter of a million 5- or 6-bit numbers (see Chapter 4). In many cases it is necessary to handle even larger arrays when digitizing high-resolution photographs; and it is often desirable to use finer quantization, to 8 or even 10 bits. (It is customary to use a power of 2 as the number of quantization levels; and one often

† In particular, if there are just two gray levels, "black" and "white," we usually represent them by 0 and 1, so that the picture becomes a Boolean array.

"exposure" when the picture was originally recorded. The second type is *gray scale transformation*, which has the aim of changing the gray scale in a uniform way throughout the picture, or perhaps throughout some region of the picture, usually in order to increase contrast and thereby make details of the picture more easily visible. An important special case of this is *histogram modification*, in which a gray scale transformation is used to give the picture a specified distribution of gray levels.

6.2.1 Gray Level Correction

A picture recording system should map object brightness into picture gray level in a monotonic fashion, and this mapping should ideally be the same at every point of the picture. In practice, however, the mapping often varies from point to point. For example, light passing along the axis of an optical system is generally attenuated less than light that passes through the system obliquely. Thus when an image is formed by the system, the parts of the image far from the axis will be attenuated relative to the parts near the axis; this phenomenon is called "vignetting." As another example, the photocathode of a vidicon may not be equally sensitive at all points; thus in a picture obtained using the vidicon, equal gray levels may not correspond to equally bright points in the scene.

If we can determine the nonuniform "exposure mapping" that produced a given picture, it is then straightforward to correct the picture, by changing the gray level of each point, to achieve the effect of a uniform mapping. Specifically, suppose that we describe the nonuniform mapping by an expression of the form

$$g(x, y) = e(x, y)\,f(x, y)$$

where $f(x, y)$ is the ideal gray level that should have resulted at picture point (x, y) had the "exposure" been uniform [i.e., $f(x, y)$ is the desired monotonic function of the object brightness at the object point corresponding to (x, y)], and $g(x, y)$ is the actual gray level at point (x, y), due to the nonuniform mapping. To determine the function $e(x, y)$, we can calibrate the picture recording system by taking a picture of a uniform field of known brightness. For such a field, f is a known constant, call it c. If $g_c(x, y)$ is the picture of the uniform field, we have $e(x, y) = g_c(x, y)/c$. Once we know $e(x, y)$, we can correct any picture $g(x, y)$ obtained by the system (as long as the calibration does not change!), since

$$f(x, y) = g(x, y)/e(x, y) = cg(x, y)/g_c(x, y).$$

In any practical gray scale, the range $[z_1, z_K]$ of gray levels used is limited by the dynamic ranges of the available display devices. The correction operation just described may give rise to gray levels outside the allowable range. One way of handling this situation is simply to change any gray level less than z_1 to z_1, and any level greater than z_K to z_K. Another possibility is to shrink and/or shift the scale of the corrected gray levels until it falls within the allowable range. (Methods of doing this will be described in Section 6.2.2.) It should also be noted that even if the uncorrected gray levels were quantized to a discrete set of values $z_1, \ldots, z_K$, the corrected levels—even though they lie in the range $[z_1, z_K]$—need not have these discrete values. Thus gray level correction of a quantized picture must be followed by requantization.

6.2.2 Gray Scale Transformation

We next consider gray scale transformations that are the same at every point of the picture (or a region), rather than varying from point to point. Such a transformation can be expressed as a mapping from the given gray scale z into a transformed gray scale z', i.e.,

$$z' = t(z)$$

We shall assume that in both the old and new gray scales, the allowable range of gray levels is the same, i.e., $z_1 \leqslant z \leqslant z_K$ and $z_1 \leqslant z' \leqslant z_K$. We can now discuss how to design gray scale transformations that have enhancing effects, e.g., that increase contrast.

It is easy to increase the contrast of a picture if the picture does not occupy its full allowable gray level range. (This can happen if the picture recording device used had a smaller dynamic range than $[z_1, z_K]$, or if the picture was originally "underexposed.") Suppose that, in the given picture f, we have $a \leqslant z = f(x, y) \leqslant b$ for all x, y, where $[a, b]$ is a subinterval of $[z_1, z_K]$. Let

$$z' = \frac{z_K - z_1}{b - a}(z - a) + z_1 = \frac{z_K - z_1}{b - a} z + \frac{z_1 b - z_K a}{b - a}$$

This simple linear gray scale transformation stretches and shifts the gray scale to occupy the full range $[z_1, z_K]$.

A similar approach can be used if *most* of the gray levels of the given picture lie in the subrange $[a, b]$. In this case, we can use the transformation

$$z' = \begin{cases} \dfrac{z_K - z_1}{b - a}(z - a) + z_1 & \text{for} \quad a \leqslant z \leqslant b \\ z_1 & \text{for} \quad z < a \\ z_K & \text{for} \quad z > b \end{cases}$$

This piecewise linear transformation stretches the $[a, b]$ interval of the

original gray scale; but it *compresses* the intervals $[z_1, a]$ and $[b, z_K]$—in fact, it collapses them to single points. This may be tolerable, however, if very few points have gray levels in these intervals, so that little information is lost when we compress.

More generally, we can stretch selected regions of the gray scale, at the cost of compressing other regions, if we want to bring out detail in the stretched regions, and we do not care about loss of information in the compressed regions. As a simple example, suppose that the gray scale range is [0, 30]; then the transformation

$$z' = \begin{cases} z/2 & \text{for} \quad z \leqslant 10 \\ 2z - 15 & \text{for} \quad 10 \leqslant z \leqslant 20 \\ (z/2) + 15 & \text{for} \quad 20 \leqslant z \leqslant 30 \end{cases}$$

compresses the gray scale by a factor of 2 in the ranges [0, 10] and [20, 30] (on the original), while expanding it by a factor of 2 in the range [10, 20].

Exercise 6. Give the equations for the transformation that stretches gray scale range [0, 10] into [0, 15], shifts range [10, 20] to [15, 25], and compresses range [20, 30] into [25, 30]. ▮

The gray scale transformations that we use can, of course, be smooth rather than piecewise linear. We can implement any desired mathematical transformation $z' = t(z)$—quadratic, logarithmic, or completely arbitrary—subject only to the restriction that the results lie in the allowable range $[z_1, z_K]$—i.e., that $z_1 \leqslant t(z) \leqslant z_K$ for all $z_1 \leqslant z \leqslant z_K$. This can always be achieved by incorporating a suitable shift and scale factor into the transformation. We can do this as follows: given any $t(z)$, let $t_1 = \min t(z)$ and $t_K = \max t(z)$ for $z_1 \leqslant z \leqslant z_K$. Then the modified transformation t' defined by

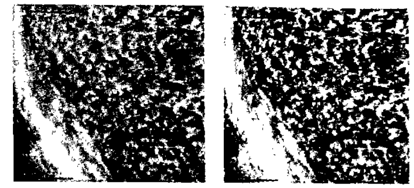
$$t'(z) = \frac{z_K - z_1}{t_K - t_1}[t(z) - t_1] + z_1$$

satisfies $z_1 \leqslant t'(z) \leqslant z_K$ for all $z_1 \leqslant z \leqslant z_K$.

Exercise 7. Give the equations for a transformation t for which $t(z)$ is a linear function of $\log z$ over the range $10 \leqslant z \leqslant 100$. ▮

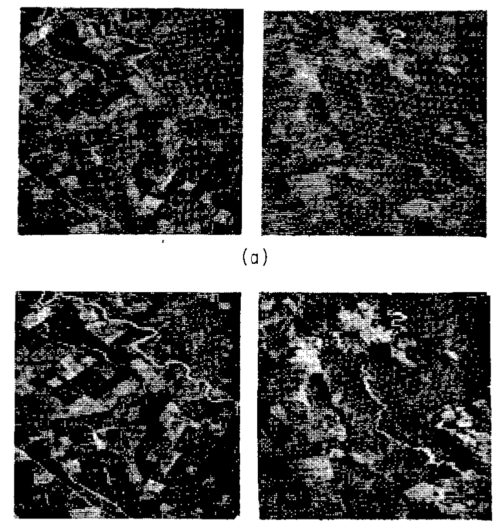
Two simple examples of contrast-stretching gray scale transformations are shown in Figs. 7 and 8. The graph of such a transformation, $t(z)$ as a function of z, is a useful aid in visualizing the effect of t. In ranges where this graph has slope <1, contrast is compressed, while slope >1 implies that contrast is stretched.

The examples of transformations considered up to now have all been monotonic [i.e., $z' \leqslant z''$ implies $t(z') \leqslant t(z'')$] and continuous. It is sometimes



(a) (b)

Fig. 7 Contrast stretching. (a) "Underexposed" picture (all gray levels in middle half of range). (b) Result of stretching the gray scale of (a) by a factor of 2.



(b)

Fig. 8 Partial contrast stretching. (a) Input pictures. (b) Result of stretching the middle third of part (a)'s gray scale by a factor of 2 while compressing the upper and lower thirds by a factor of 2.

of interest, however, to consider nonmonotonic discontinuous transformations in which different ranges of input gray levels are mapped into the same range of output levels. As a simple example, if the input range is [0, 30], the discontinuous transformation

$$t(z) = \begin{cases} 3z, & 0 \leqslant z \leqslant 10 \\ 3(z-10), & 10 < z \leqslant 20 \\ 3(z-20), & 20 < z \leqslant 30 \end{cases}$$

Fig. 9 Discontinuous, nonmonotonic contrast stretching. (a) Input picture (same as Fig. 2b of Chapter 8). (b) Result of stretching each third of part (a)'s nonzero gray levels to cover the full gray level range.

maps each third of this range into [0, 30]. Within these subranges, we have threefold contrast stretching; but as we cross from one range to another, strong false contours are introduced, as illustrated in Fig. 9.†

This discussion has treated the input gray scale as though it were continuous rather than quantized. If it is, in fact, quantized, say to the K discrete values $z_1, \ldots, z_K$, then any gray scale transformation t can only produce K discrete output values $t(z_1), \ldots, t(z_K)$, some of which may be equal.‡ Nevertheless, contrast stretching can be advantageous, since it enables us to space (some of) the output values farther apart, so that they become more clearly distinguishable. In a well-designed gray scale, consecutive levels z_i, z_{i+1} should not be easily distinguishable; in fact, if they were, we could never get the impression of continuously varying gray levels in a picture. Thus detail that is not sharply delineated in the input is enhanced in the output when we spread the gray levels. Note, however, that once the levels have been spread far enough apart to become easily distinguishable, there is little to be gained in spreading them still farther apart, since all the available information (in the gray level range that has been stretched) has already been brought out. Note also that in ranges where the gray scale is compressed, information is lost, since when we requantize, several input levels may be mapped into the same output level.

If a picture's gray scale has been distorted by a known gray scale transformation $z' = t(z)$, the distortion can in principle be corrected by applying

† Another important "contrast-stretching" technique is to map the gray levels of a picture into *colors*—e.g., low levels into shades of red; higher ones into orange shades; still higher ones into yellow, and so on. This can greatly enhance the visibility of detail in the picture, because the eye is more sensitive to differences in hue than it is to differences in brightness.

‡ See, however, Section 6.2.3, where we discuss how to map a single input gray level into more than one output level.

the inverse transformation $z = t^{-1}(z')$. For example, this approach can be used to correct for the effects of nonlinearities in the gray scales of display devices, or of recording media such as photographic film. In practice, of course, implementation of t^{-1} may be subject to the difficulties previously discussed.

6.2.3 Histogram Modification

Given a picture f, let $p_f(z)$ denote the relative frequency with which gray level z occurs in f, for all z in the gray level range $[z_1, z_K]$ of f. The graph of $p_f(z)$ as a function of z, normalized so that $\int_{z_1}^{z_K} p_f(z)\,dz$ is equal to the area of f, is called the *histogram* of f. If f is quantized, and has gray levels $z_1, \ldots, z_K$, its histogram can be represented as a bar graph having K bars. As we shall see in Chapters 8 and 10, the histogram of f can provide useful information about how to segment f into parts, and it also serves as a basis for measuring certain textural properties of f. Note that for any $z_1 \leqslant a \leqslant b \leqslant z_K$, the integral $\int_a^b p_f(z)$ measures how heavily the gray scale range $[a, b]$ is populated, i.e., what fraction of f's points have their gray levels in that range.

In this section we describe how to transform a picture's gray scale so as to give the picture a specified histogram $q(z)$. The following are some cases where this type of transformation might be required:

(a) If we want to quantize a picture f to K discrete levels in such a way as to minimize quantization error (Section 4.3.1), the K levels should be spaced close together in heavily populated regions of f's gray scale, but they can be farther apart in sparse regions. One way of doing this is to pick the levels at the midpoints between the successive K-tiles of f's histogram; this means that when we quantize, just one Kth of the points of f will be quantized to each of the levels. This "tapered" quantization scheme thus transforms f's histogram into a "flat" bar graph in which all the bars have equal height.

(b) Suppose that we want to compare two pictures f_1 and f_2 in order to (say) detect differences between them. If the pictures were obtained under different lighting conditions, we must somehow compensate for this, since otherwise they will have different gray levels at every point even if they are pictures of the same scene. One way to carry out this compensation might be to transform the gray scale of f_1 so that its histogram matches that of f_2, or to transform both pictures so that they have some standard histogram. (On picture matching see Section 8.3.)

(c) We often want to measure certain properties of a picture f in order to classify or describe it. If these properties depend on the gray levels that are present in f, their values will be sensitive to the lighting conditions under which f was obtained. This sensitivity can be reduced by "normalizing" f so that it

Exhibit B

CGSD - Gamma Correction Explained

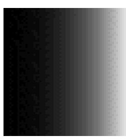
What is Gamma Correction?

In the field of Computer Graphics, one often hears the phrase "gamma correction." What is this strange sounding thing and why does it matter to you?

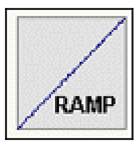
Gamma correction matters if you have any interest in displaying an image accurately on a computer screen. Gamma correction controls the overall brightness of an image. Images which are not properly corrected can look either bleached out, or too dark. Trying to reproduce colors accurately also requires some knowledge of gamma. Varying the amount of gamma correction changes not only the brightness, but also the ratios of red to green to blue. (Example of this color phenomenon).Gamma correction also plays a big role in making images for the WWW.

To explain gamma correction we will begin with where you are looking - your computer monitor.

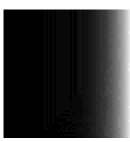
Almost every computer monitor, from whatever manufacturer, has one thing in common. They all have a intensity to voltage response curve which is roughly a 2.5 power function. Don't be afraid, this just means that if you send your computer monitor a message that a certain pixel should have intensity equal to x, it will actually display a pixel which has intensity equal to x ^ 2.5 Because the range of voltages sent to the monitor is between 0 and 1, this means that the intensity value displayed will be less than what you wanted it to be. (0.5 ^ 2.5 = 0.177 for example) Monitors, then, are said to have a gamma of 2.5



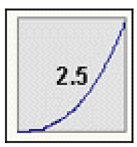
Sample Input to Monitor



Graph of Input



Output from Monitor

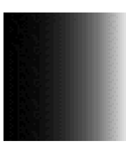


Graph of Output **L = V ^ 2.5**

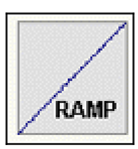
Note: The grayscale images will not look very good on 8-bit color computers. Also the gamma correction for these images is 1.0 so they were actually designed to be viewed on a system such as a Sun or a PC with no hardware correction. They may appear brighter on other systems. The important thing here is the relative difference that you see.

To correct this annoying little problem, the input signal to the monitor (the voltage) must be "gamma corrected".

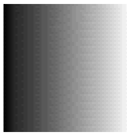
The solution, fortunately, is a simple one. Since we know the relationship between the voltage sent to the monitor and the intensity which it produces, we can correct the signal before it gets to the monitor. The signal is adjusted so that it is essentially the complement of the curve shown above. There are other considerations as well when one speaks of a "correct" image. These include the ambient light in a room where the computer is, the brightness and contrast settings on the monitor, and finally personal taste.



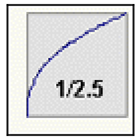
Sample Input



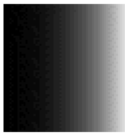
Graph of Input



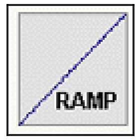
Gamma Corrected Input



Graph of Correction **L' = L ^ (1/2.5)**



Monitor Output



Graph of Output

If gamma correction is done properly for the computer system, then the output should accurately reflect the image input.

Note that the task of gamma correction is accomplished by raising the input value to the 1/2.5 power. This is referred to as a gamma correction of 2.5. because we are correcting the input for a monitor whose gamma is 2.5

Real World Application

In the real world, it isn't quite this simple, especially when an image needs to look good on different systems, or platforms.

As we mentioned above, most monitors work in about the same way with respect to gamma correction. Most computers, or more specifically, most computer systems, do not work in exactly the same way, however.

By computer systems we mean everything from the software that is running (like Netscape) to the graphics cards installed, to the standard hardware on the motherboard. Different computers do different things and many "systems" have different configurations of all of the above things.

Macintoshes, for example, have partial gamma correction built-in to their hardware. Silicon Graphics computers also have built-in gamma correction, but it is different from the Macintosh. Suns and PCs have no standard built-in gamma correction but some graphics cards installed in these computers may provide this functionality.

System Gamma

The idea of system gamma, is the gamma correction that should be applied in the software to reproduce an accurate image on the monitor for an uncorrected image on a particular computer "system."

Macintosh

> The Macintosh has built-in gamma correction of 1.4. This means that after the software sends the signal to the framebuffer, there are internal hardware corrections which will further process the signal, specifically by gamma correcting it another 1.4 - That is, the signal is raised to the 1/1.4. Therefore, to get full correction, the software itself should first adjust the signal by raising it to the 1/1.8 power. (2.5/1.4 = 1.8) Thus the system gamma on a Macintosh is 1.8.
>
> Note some graphics cards in Macintoshes may have their own software to change the standard gamma and Adobe Photoshop 3.0 is now released with a gamma control panel from Knoll software which allows the user to change the system gamma of their Macintosh. The 1.8 standard is still accepted as the universal Mac System Gamma, but users should be aware that a Mac can be set differently. The Knoll software control panel for the Mac rewrites the look up table, (LUT) with a value of g/2.5 where g is the gamma the user selects. Thus selecting 1.8 will rewrite the LUT with 1.8/2.5 = 1/1.4 - the default setting. (The values in the LUT are 1/1.4 and this is called a 1.4 correction)

SGI

The SGI is similar to the Macintosh but instead of a hardware correction of 1.4 the SGI applies gamma correction of 1.7. Thus the system gamma for an SGI is 2.5/1.7 or roughly 1.5. Sometimes you may see that an SGI has a system gamma of 1.4. This calculation is made on the assumption that monitors have a response curve closer to a 2.4 power function.

SGI's also come with a utility to rewrite the internal hardware correction. These values are stored in a look up table, (LUT) and can be altered. The default is 1/1.7 as mentioned above. (The values in the table are 1/1.7, so we call this a 1.7 correction) Sometimes the value in the LUT may be referred to as the SGI system gamma. This is not the definition used on other platforms. Unlike the Mac gamma control panel, the SGI gamma utility will rewrite the LUT with the actual value set by the user. Gamma Definitions

Suns and PCs

Suns and PCs have no standard hardware correction (although certain graphics cards for these platforms may) and therefore their system gammas are roughly 2.5. (More about Sun's SX hardware and gamma)

Common graphics software such as Adobe Photoshop allows the user to set the gamma correction value they want. (In Photoshop it is found in Monitor Setup under Preferences under the File Menu.)
More about software gamma correction

Exhibit C

REDACTED
IN ITS ENTIRETY

Exhibit D

United States Patent [19]

Iida et al.

[11] 4,394,688

[45] Jul. 19, 1983

[54] **VIDEO SYSTEM HAVING AN ADJUSTABLE DIGITAL GAMMA CORRECTION FOR CONTRAST ENHANCEMENT**

[75] Inventors: **Hitoshi Iida**, Bedford; **Pay-Shin King**, Newton, both of Mass.

[73] Assignee: **Hamamatsu Systems, Inc.**, Waltham, Mass.

[21] Appl. No.: **296,068**

[22] Filed: **Aug. 25, 1981**

[51] **Int. Cl.**³ **H04N 5/14**; H04N 5/20

[52] **U.S. Cl.** **358/160**; 358/164; 358/163; 358/166; 358/169; 382/54

[58] **Field of Search** 358/160, 163, 164, 166, 358/37, 168, 169, 903, 111; 364/515

[56] **References Cited**

U.S. PATENT DOCUMENTS

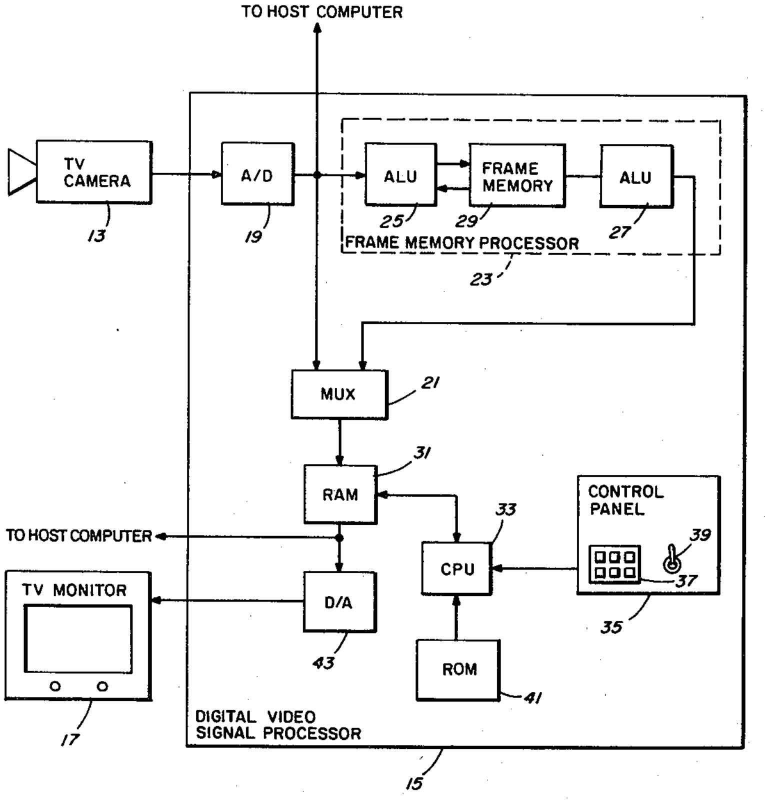
3,800,078	3/1974	Cochran et al.	358/166 X
4,148,070	4/1979	Taylor	358/160
4,242,707	12/1980	Budai	358/160
4,335,427	6/1982	Hunt et al.	358/166 X

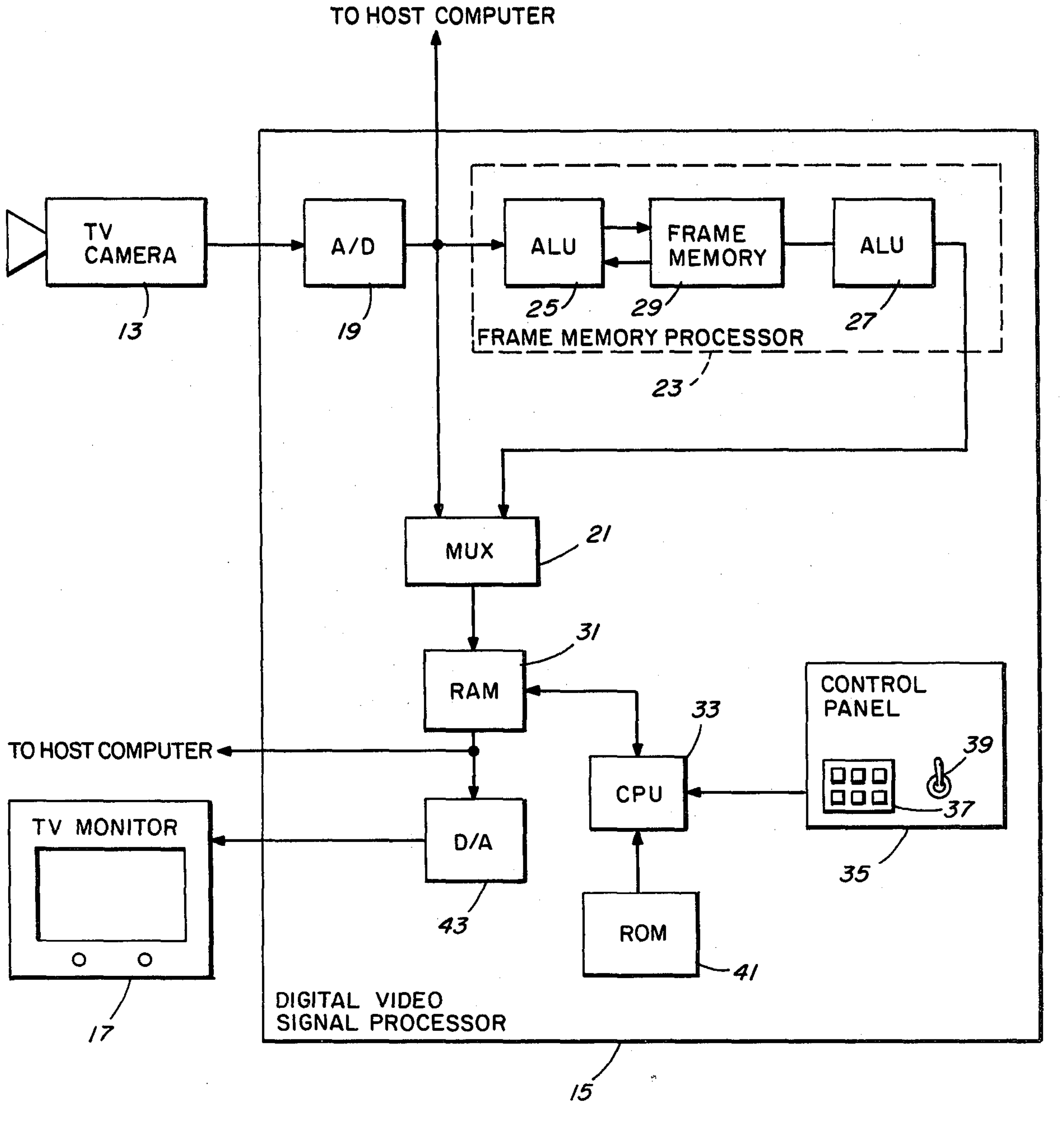
Primary Examiner—Robert L. Richardson
Attorney, Agent, or Firm—Irving M. Kriegsman

[57] **ABSTRACT**

A video system having a television camera, a digital video signal processor coupled to the output of the television camera and a television monitor coupled to the output of the digital video signal processor is disclosed. The digital video signal processor includes an analog to digital converter for converting analog video signals into video data, a frame memory processor for processing and temporarily storing the video data, a random access memory device in which the video data is altered in accordance with the contents of a table-look-up temporarily written therein, a read only memory device containing a plurality of different table-look-ups, each table-look-up containing data representing a different gamma correction, a central processing unit for obtaining a table-look-up from the read only memory device and then writing the table-look-up into the random access memory device and a manually operated control device coupled to the central processing unit for selecting which table-look-up is read out from the read only memory device and then written into the random access memory device and a digital to analog converter for converting the processed video data into analog video signals.

9 Claims, 1 Drawing Figure




TO HOST COMPUTER
TV CAMERA
13
A/D
19
ALU
FRAME MEMORY
ALU
25
29
27
FRAME MEMORY PROCESSOR
23
MUX
21
RAM
31
TO HOST COMPUTER
CONTROL PANEL
33
39
CPU
37
35
TV MONITOR
D/A
43
ROM
41
17
DIGITAL VIDEO SIGNAL PROCESSOR
15

VIDEO SYSTEM HAVING AN ADJUSTABLE DIGITAL GAMMA CORRECTION FOR CONTRAST ENHANCEMENT

BACKGROUND OF THE INVENTION

The present invention relates generally to video systems and more particularly to a video system which includes an adjustable digital gamma correction which is used to selectively emphasize or enhance the contrast of a video picture over different regions of interest.

In a television system the relationship between the brightness of a portion of an object and the brightness of the corresponding portion of the image is generally expressed by the formula:

$$y = x^{\gamma}$$

where y is the magnitude of the output signal, x is the magnitude of the input signal and γ is the power, referred to as the gamma, to which x must be raised to be equal to y. In order to determine the overall gamma of a television system, the gamma of the television camera and the gamma of the television monitor or receiver are multiplied together. In an ideal or distortionless system the overall gamma is 1.0. Unfortunately, in most all television cameras the gamma (which is determined by the composition of the photosensitive material in the vidicon) is between around 0.6 to 0.5 while in most all television monitors the gamma (which is determined by the composition of the phosphorescent material in the screen) is designed to be about 2.2. Consequently, the overall gamma is normally not equal to 1.0 and the contrast of the resulting image is somewhat distorted (i.e. in certain areas the contrast is greater than it should appear and in other areas the contrast is less than it should appear).

In order to correct for this distortion, a type of analog electrical circuit called a gamma correction circuit is normally incorporated into the system. The circuit provides a gamma which when multiplied together with the gamma of the television camera and the gamma of the television monitor produces an overall gamma in the system of around 1.0. These gamma correction circuits are normally built into the television camera or a control module for the television camera and are usually adjustable within a small range, such as from 0.85 to 1.0, to compensate for variations that may be present in the gamma of the particular vidicon tube used in the television camera. Once set to the particular value needed to produce an overall gamma of 1.0 (or as close to 1.0 as is possible), the gamma of the gamma correction circuit is generally not changed. However, in some closed circuit television systems used for surveillance purposes it is known to provide a knob or other manually adjustable means at the television monitor for adjusting the gamma produced by the gamma correction circuit for the purpose of intentionally distorting the contrast over areas of interest where the lighting is poor and the resulting image difficult to perceive. The amount of intentional distortion that can be produced, however, is limited to the small range of adjustability in the analog gamma correction circuit.

It is known to intentionally distort the contrast of an image formed in video microscope systems used in industrial and research applications to examine characteristics and properties of very small objects in order to improve the visibility of the objects being examined by selectively manipulating the gain and offset knobs in the video camera and the diaphragm and compensator settings in the microscope. An example of this technique of contrast enhancement may be found in a publication entitled Video-Enhanced Contrast Polarization (AVEC-POL) Microscopy appearing in Cell Motility 1:275–289 (1981), Alan R. Liss, Inc.

It is also known to convert analog video signals into video data for temporary or permanent storage and/or digital signal image processing. One known type of digital signal image processing that is often performed to improve the quality of an image is noise reduction. An example of a known digital type image processing system may be found in U.S. Pat. No. 4,240,113, to Michael et al. Another example of a digital image processing system is described in Hamamatsu Systems Inc. Product Bulletin/2001 Rev. 2 2-81.

It is an object of this invention to provide a new and improved video system which is especially suited for use in, but not exclusively limited to, industrial and research applications.

It is another object of this invention to provide a novel method and system for selectively manipulating the contrast of a video image.

It is a further object of this invention to provide a video system having an adjustable digital gamma correction.

It is yet still another object of this invention to provide a novel method and system for selectively manipulating the contrast of a video image over low intensity areas.

It is a further object of this invention to provide a novel method and system for selectively manipulating the contrast of a video image over high intensity areas.

It is yet still another object of this invention to provide a video system in which the gamma is adjustable and useable over a range from 0.1 or lower to 3.0 or higher.

It is another object of this invention to provide a system and method for digitally adjusting the gamma of a video system in order to provide contrast enhancement in selected areas of interest.

SUMMARY OF THE INVENTION

A video system constructed according to the teachings of the present invention includes a television camera, a digital video signal processor coupled to the output of the television camera and a television monitor coupled to the output of the digital video signal processor. The digital video signal processor includes an analog to digital converter for converting analog video signals from the television camera into video data, a random access memory device through which the video data is passed and in which the video data is altered in accordance with the contents of a table-look-up temporarily written therein, a read only memory device containing a plurality of different table-look-ups for use in the random access memory device, each table-look-up containing data representing a different gamma correction, a central processing unit for obtaining a table-look-up from the read only memory device and then writing the table-look-up so obtained into the random access memory device in response to control signals applied thereto, a manually operated control device for applying control signals to the central processing unit for selecting which table-look-up is read out from the read only memory device and then written into the random access memory device and an analog to digital

converter for converting the processed video data into analog video signals. In the operation of the digital video system, the contrast of the video picture appearing the television monitor is adjusted for optimum viewing conditions over an area of interest by changing the particular table-look-up in the random access memory device until the most favorable picture is produced.

The foregoing and other objects as well as many advantages of the invention will appear from the description to follow. In the description, reference is made to the accompanying drawings which form a part thereof, and in which is shown by way of illustrating, specific embodiments for practicing the invention. These embodiments will be described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural changes may be made without departing from the scope of the invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is best defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings wherein like reference numerals represent like parts, the sole FIGURE is a simplified block diagram of a video system including a digital video signal processor constructed according to the principles of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to the drawings, there is illustrated in the sole FIGURE a simplified block diagram of a video system constructed according to the teachings of the present invention and identified generally by reference numeral **11**.

Video system **11** includes a television camera **13** for generating analog video signals of an object or scene (or an optical image of an object or scene such as may be formed by a microscope), a digital video signal processor **15** for digitally processing the video signals obtained from the TV camera **13** and a television monitor **17** for displaying an image of the processed video signals.

The digital video signal processor **15** includes an analog to digital converter **19** for converting the analog video signals from TV camera **13** into video data. The video data from analog to digital converter **19** is transmitted to one of two inputs of a multiplexer **21** and to the input of a frame memory processor **23**. The video data from analog to digital converter **19** may also be transmitted to a host or main computer (not shown) for permanent storage and processing, if desired.

In the frame memory processor **23**, video data of a single frame is temporarily stored and processed either before or after storage. The frame memory processor **23** is shown in the FIGURE as including a pair or arithmetic logic units **25** and **27** and a frame memory **29**. Frame memory processor **23** performs various known arithmetic type video signal processing functions, such as summing, averaging or differencing, the particular construction of frame memory processor **23** to perform these functions for purposes such as noise reduction not being considered a part of the invention and the particular components shown therein being for illustrative purposes only. Frame memory **29** may comprise a pair of Intel chips number 2117. An example of a known frame memory processor capable of performing adding, substracting and averaging type signal processing is described in the above referenced Hamamatsu Systems Inc. Product Bulletin/2001, Revision 2, 2/81. The output of the frame memory processor **23** is transmitted to the other input of multiplexer **21**.

The video data from multiplexer **21**, which is obtained either from analog to digital converter **19** or frame memory processor, is transmitted to a high speed random access memory device **31**, where it is modified by a table-look-up which is temporarily written therein. Random access memory device **31** may comprise a pair of Fairchild chips number 93L422 and conventional associated logic circuitry. Random access memory device **31** is loaded with the table-look-up which is used to modify the video data from a central processing unit (CPU) **33** which controls the overall operations of the digital video signal processor **15** through signals sent over appropriate control lines (not shown). CPU **33** may be, for example, an Intel chip number 8080. The program for operating CPU **33** is stored in a memory (not shown) and instructions for executing the operating program are entered through a manually operated control panel **35** which includes a keyboard **37** and a joystick **39**.

The table-look-up which is sent to random access memory device from CPU **33** is obtained from a bank of different table-look-ups permanently stored in a read only memory device **41** which is coupled to CPU **33**. Each one of the table-look-ups in memory device **41** is for a different gamma correction. For example, there may be a bank of thirty table-look-ups, with each table-look-up having a different gamma correction, the smallest gamma correction table being 0.1 or smaller and the largest gamma correction table being 3.0 or larger. As can be appreciated, if the gamma resulting from TV camera **13** and TV monitor **17** is, for example, 1.32 a set of gamma correction tables having a range of 0.1 to 3.0 will enable the overall gamma to be changed from 0.132 to 3.966. Read only memory device **41** may comprise a pair of Intel chips number 2716 and associated logic circuitry.

The modified output data from random access memory device **31** is fed into a digital to analog converter **43** where it is converted into analog video signals. The modified output data may also be sent to the host computer, if desired. The image corresponding to the video output signals from digital to analog converter **43** is displayed on TV monitor **17**.

In the operation of the digital video signal processor **15**, the particular table-look-up that is read out from the read only memory device **41** and written into the random access memory is controlled through the manually operated control panel **35**. For example, the CPU **33** may be programmed so that the specific table-look-up written into the random access memory **31** from the read only memory **41** is determined by the angular position of the joy stick **39**. Alternatively CPU **33** may be programmed so that different look-up-tables can be moved from read only memory **41** to random access memory **31** by depressing different keys or combinations of keys on the keyboard **37**. As can be appreciated, the gamma correction applied to the video data can thus be very easily and very quickly changed over a range limited solely the number of different tables stored in the read only memory device **41** and the gamma values preselected for the individual tables.

In using the digital video signal processor **15** to manipulate contrast, data sent to multiplexer **21** either

directly from analog to digital converter **19** or from frame memory processor **23** is fed from multiplexer **21** into random access memory **31**, the particular data selected being controlled by CPU **33**. The gamma correction table inserted into random access memory device **31** is than changed until the most favorable image is formed on the screen of the TV monitor **17**. By changing the gamma correction over a portion of or over the entire range of table-look-ups, areas of interest in the resulting picture may be seen which might not otherwise be visually perceptible.

As is known, for certain applications such as viewing video pictures of X-rays, it is benefical to emphase contrast in low intensity areas while in other applications such as in video microscopy it is beneficial to emphasize contrast in high intensity areas. Thus, in certain instances low gamma corrections are desirable while in other instances high gamma corrections are desirable.

As is also known, at very high or very low gammas, noise represents a problem that can very adversely effect the resulting picture. However, by processing the video data through frame memory processor **23**, the noise can be easily reduced or substantially eliminated. Therefore, when using very high or very low gammas, the video data should be processed for noise reduction in the frame memory processor **23**.

The above description is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly all suitable modifications and equivalents may be resorted to, falling within the scope of the invention as claimed.

What is claimed is:

1. A video system comprising a television camera for converting visual information into analog video signals, a digital video signal processor for digitally processing said anolog video signals and a television monitor for displaying an image of the processed analog video signals, said digital video signal processor including:

a. an analog to digital converter for converting the analog video signals into video data,

b. a first memory device for modifying the video data according to the particular contents contained therein,

c. a second memory device, said second memory device having stored therein a plurality of table-look-ups, each table-look-up corresponding to a different gamma correction,

d. a central processing unit for controlling the operations of the digital video signal processor, said operations including reading out one of said table-look-ups in said second memory device and writing said read data into said first memory device,

e. a manually operated control device for controlling the operations of the central processing unit, said control device including means for selecting the particular table-look-ups to be read by said central processing unit, and

f. a digital to analog converter for converting the modified video data from said first memory device into analog video signals.

2. The video system of claim **1** and wherein said first memory device comprises a pair of high speed RAMS.

3. The video system of claim **1** and further including a frame memory processor for processing and/or storing a single frame.

4. The video system of claim **1** and wherein the means for selecting the particular table-look-up to be read by the central processing unit comprises a joystick.

5. A method of manipulating video picture data for the purpose of enhancing contrast over certain areas of interest comprising:

a. passing said video picture data through a first memory device which is arranged to modify the video picture data according to the contents of a table-look-up contained therein,

b. providing a second memory device having therein a plurality of different table-look-ups, each table-look-up corresponding to a different gamma correction, and

c. selectively reading out one of said table-look-ups from said second memory device and writing said table-look-up so read into said first memory device.

6. A digital video signal processor for processing analog video signals comprising:

a. an analog to digital converter for converting the analog video signals into video data,

b. a first memory device for modifying the video data according to the particular contents contained therein,

c. a second memory device having therein a plurality of table-look-ups, each table-look-up constituting a different gamma correction,

d. a central processing unit for moving one of the table-look-ups from the second memory device to the first memory device and

e. control means for selecting which table-look-up is moved from the second memory device to the first memory device.

7. A digital video signal processor according to claim **6** and wherein said first memory device comprises a pair of high speed RAMS.

8. A digital video signal processor according to claim **6** and wherein including a frame memory processor for processing and/or storing a single frame.

9. A digital video signal processor according to claim **6** and wherein the means for selecting the particular table-look-up to be read by the central processing unit comprises a joystick.

* * * * *

Exhibit E

THE OXFORD ENGLISH DICTIONARY

SECOND EDITION

Prepared by
J. A. SIMPSON *and* E. S. C. WEINER

VOLUME III
cham–creeky

CLARENDON PRESS · OXFORD
1989

Oxford University Press, Walton Street, Oxford OX2 6DP
Oxford New York Toronto
Delhi Bombay Calcutta Madras Karachi
Petaling Jaya Singapore Hong Kong Tokyo
Nairobi Dar es Salaam Cape Town
Melbourne Auckland
and associated companies in
Berlin Ibadan

Oxford is a trade mark of Oxford University Press

British Library Cataloguing in Publication Data
Oxford English dictionary.—2nd ed.
1. English language-Dictionaries
I. Simpson, J. A. (John Andrew), 1953-
II. Weiner, Edmund S. C., 1950-
423
ISBN 0-19-861215-X (vol. III)
ISBN 0-19-861186-2 (set)

Library of Congress Cataloging-in-Publication Data
The Oxford English dictionary.—2nd ed.
prepared by J. A. Simpson and E. S. C. Weiner
Bibliography: p.
ISBN 0-19-861215-X (vol. III)
ISBN 0-19-861186-2 (set)
1. English language—Dictionaries. I. Simpson, J. A.
II. Weiner, E. S. C. III. Oxford University Press.
PE1625.087 1989
423—dc19 88-5330

Data capture by ICC, Fort Washington, Pa.
Text-processing by Oxford University Press
Typesetting by Filmtype Services Ltd., Scarborough, N. Yorks.
Manufactured in the United States of America by
Rand McNally & Company, Taunton, Mass.

continuity (kɒntɪˈnjuːɪtɪ). [a. F. *continuité* (16th c.), ad. L. *continuitāt-em*, f. *continu-us*: see -ITY.] The state or quality of being continuous.

1. Of material things: The state or quality of being uninterrupted in extent or substance, of having no interstices or breaks; uninterrupted connexion of parts; connectedness, unbrokenness.

1543 [see 5]. **1570** DEE *Math. Pref.* D j, Fyre and Ayre.. will descend, when..their Continuitie should be dissolued. **1607** TOPSELL *Four-f. Beasts* (1673) 38 Inflaming the body, loosing the continuity of the parts. **1615** CROOKE *Body of Man* 307 Now there is no continuity betweene the vmbilicall veine and the hollow veine. **1646** SIR T. BROWNE *Pseud. Ep.* II. i. 55 Continuity of parts is the cause of perspicuity. **1727–51** CHAMBERS *Cycl.*, *Continuity* is usually defined, among schoolmen, the immediate cohesion of parts in the same quantum. **1804** WELLINGTON in Gurw. *Disp.* III. 59 The continuity of the frontier. **1813** BAKEWELL *Introd. Geol.* (1815) 52 Sometimes the continuity of rocks and strata is.. broken. **1855** BAIN *Senses & Int.* I. ii. §17 (1864) 46 The continuity of the cord with the brain is necessary.

2. a. Of immaterial things, actions, processes, etc.: The state or quality of being uninterrupted in sequence or succession, or in essence or idea; connectedness, coherence, unbrokenness.

1603 HOLLAND *Plutarch's Mor.* 1356 All that shall be, hath a stint and dependance of that which is, by a certeine continuitie, which proceedeth from the beginning to the end. **1751** HARRIS *Hermes* vii. (1786) 101 We may gain some idea of Time, by considering it under the notion of a transient continuity. **1820** W. IRVING *Sketch Bk.* I. 10 In travelling by land there is a continuity of scene, a connected succession of incidents that carry on the story of life. **1842** W. GROVE *Corr. Phys. Forces* Pref. (ed. 6) 16 The continuity of attention necessary for the proper evolution of a train of thought.

b. *law* or ***principle of continuity***: the principle that all change, sequence, or series in nature is continuous, and that nothing passes from one state to another *per saltum*.

The phrase originated with Leibnitz. In 1687 he laid down as a general principle, that where there is continuity between data, such that one case continually approaches and at length loses itself in another, there will be a corresponding continuity in results or properties. For example, it is a property of the ellipse that all rays from the one focus are reflected from the curve to the other; in the parabola all such rays reflected at the curve are parallel; if there be given a series of ellipses continually approaching the parabola by the continuous increase of distance between the foci, the focal radii of these will continuously approach the relation of parallelism, so as at length to differ from it by less than any assignable amount. This was according to Leibnitz 'a principle of general order', having its origin in the mathematical infinite, absolutely necessary in Geometry, but holding good also in Physics, because the Sovereign Wisdom, the source of all things, acts as a perfect Geometer, and according to a harmony that admits of no addition. In 1702 he referred to this principle as 'the law of continuity', and claimed that it operates in all natural phenomena; and in his *Nouveaux Essais*, he declared it to be part of his 'Law of Continuity' that everything in nature goes by degrees, and nothing *per saltum*.

[**1687** LEIBNITZ *Lettre à Mr. Bayle* Wks. Erdm. 104. **1690** —— *Lettre à Mr. Arnauld* ibid. 107 Chacune de ces substances contient dans sa nature legem continuationis seriei suarum operationum. **1702** —— *Repl. aux Refl. de Bayle* ibid. 189/2 Qu'il ne se rencontre jamais rien, où la loi de la continuité (que j'ai introduite, et dont j'ai fait la première mention dans les *Nouvelles de la République des Lettres* de Mr. Bayle), et toutes les autres règles les plus exactes des Mathématiques soient violées. *a* **1716** —— *Nouv. Ess.* IV. xvi, Tout va par degrés dans la nature et rien par saut, et cette règle, à l'égard des changements, est une partie de ma loi de la continuité.] **1753** CHAMBERS *Cycl.* Suppl. s.v., An eminent mathematician has supposed what he calls a law of continuity to obtain in the universe, by which law every thing that is executed or done in nature, is done by infinitely small degrees. **1812–6** PLAYFAIR *Nat. Phil.* (1819) I. 271 When bodies, whether solid or fluid, act on one another by impulse or percussion, in such a manner that their action is subject to the law of continuity. **1830** HERSCHEL *Stud. Nat. Phil.* 189 It prevents a breach of the law of continuity between transparent and opake bodies. **1841** J. R. YOUNG *Math. Dissert.* ii. 74 That the angle changes at once from 90° to zero, is to admit so palpable a violation of the principle of continuity..that, etc. **1862** MULCAHY *Mod. Geom.* (ed. 2). **1878** TAIT & STEWART *Unseen Univ.* (1880) p. xii, We endeavour to show..that immortality is strictly in accordance with the principle of Continuity (rightly viewed).

c. ***equation of continuity***, in *Hydrodynamics*: the equation connecting the rate of change of density of a fluid within any closed surface constantly full of fluid with the flow of fluid through the surface.

1836 T. WEBSTER *Equilibr. & Motion of Fluids*. **1880** HAUGHTON *Phys. Geog.* iii. 141. **1882** MINCHIN *Unipl. Kinemat.* §93.

3. The state or quality of being continuous in time; uninterrupted duration. *rare.*

1646 SIR T. BROWNE *Pseud. Ep.* IV. xiii, Wee need not have recourse unto any starre but the Sunne and the continuity of its action. **1840** MRS. BROWNING *Drama of Exile* Poems 1850 I. 27 Their stedfast continuity of gaze. **1841** BREWSTER *Mart. Sc.* II. iv. (1856) 146 A painful disease, which had its origin in the severity and continuity of his studies.

4. a. quasi-*concr*. A continuous or connected whole; a continuous or unbroken course or series. (Of material or immaterial things.)

1601 HOLLAND *Pliny* II. 423 Running throughout one continuity without interruption. *a* **1619** FOTHERBY *Atheom.* II. ix. §3 (1622) 296 All magnitudes and continuities are deduced from one originall prick. **1644** MILTON *Areop.* (Arb.) 70 When every stone is laid artfully together, it cannot be united into a continuity, it can but be contiguous in this world. **1809–10** COLERIDGE *Friend* (1865) 219 A chain that ascends in a continuity of links.

b. A part continuous with something else. *rare.*

1809 W. IRVING *Knickerb.* (1861) 248 The New-Netherlands..a continuity of the territory taken possession of..by the Pilgrims, when they landed on Plymouth Rock.

5. ***solution of continuity***: the fact or condition of being or becoming discontinuous; fracture, rupture, breakage, 'break'. Orig. used of wounds, etc. in an animal body; thence also in other senses.

1543 TRAHERON tr. *Vigo's Chirurg.* (1586) 12 The heart can not suffer solution of continuitie without death. **1661** BRAMHALL *Just Vind.* ii. 14 Schisme is an exteriour breach, or a solution of continuity in the body Ecclesiastick. **1707** *Curios. in Husb. & Gard.* 77 The Solution of Continuity may hinder the Juice from mounting. **1790** BURKE *Fr. Rev.* 24 With what address this temporary solution of [historical] continuity is kept from the eye. **1877** TYNDALL in *Daily News* 2 Oct. 2/5 We are brought without solution of continuity into the presence of problems, which..lie entirely outside the domain of physics.

6. a. *Cinemat.* A detailed scenario for a cinema film; also, the maintenance of consistency or a continuous flow of action in successive shots or scenes of a cinema or television film. orig. *U.S.*

1921 *Collier's* 25 June 26/3 It is a hobby of mine never to pay no attention to a continuity, as it only gets a man balled up. **1926** G. F. BUCKLE *Mind & Film* I. 18, I am deliberately using the word scenario here instead of continuity (which is the correct name for the working script) in order to avoid confusion when discussing faults in the scenario which result in bad continuity in the film. **1927**, etc. [see sense 7 below]. **1930** *Times* 12 July 4/6 Mr. Knoblock became joint author..of the scenario of the talking film and he also wrote the 'continuity' or stage directions. **1940** F. SCOTT FITZGERALD *Let.* 11 May (1964) 116 I've written a really brilliant continuity..it seems to be a last life line that Hollywood has thrown me. **1940** *War Illustr.* 12 Jan. p. ii/2 Touching this matter of 'continuity'—to use a word from film-technique. **1951** 'J. WYNDHAM' *Day of Triffids* vi. 116 Sandra is our professional remembrancer—continuity is her usual work.

b. A series of linking announcements, interpolations, or the like in a radio programme or broadcast; the maintenance of a continuous sequence in broadcasting (see quot. 1941).

1934 *B.B.C. Year-Bk.* 107 The Ceremony of the Keys is a good example of a broadcast which requires elaborate technical arrangements to ensure 'continuity'. **1941** *B.B.C. Gloss. Broadc. Terms* 7 *Continuity*, (1) structure of verse or prose, linking sections of a dramatic or of a magazine programme; (2) announcements or interlude material filling intervals between programmes in a sequence of programmes. **1968** *Listener* 4 Jan. 28/2 *All the Best*..is..full of limp interviews and badly written continuity.

7. *attrib.*, as ***continuity announcement, announcer, clerk***; **continuity girl** *Cinemat.*, a woman who is responsible for ensuring that there are no discrepancies of detail between linked scenes filmed at different times; **continuity studio** (see quot. 1941); **continuity suite** (see quot. 1962); **continuity title**, an explanatory title inserted into a film to ensure continuity; **continuity writer**, a writer of continuity titles.

1962 A. NISBETT *Technique of Sound Studio* i. 17 The output of individual studios is..linked together by ..*continuity announcements. *Ibid.*, *Continuity announcer. **1927** *Sunday Express* 29 May 10 Promising to let her be a *continuity clerk if she did not get ahead as an actress. **1933** 'I. HAY' & 'A. ARMSTRONG' *Orders are Orders* II. 46 Meet Miss Marigold, my secretary and *continuity girl. **1937** M. ROBINSON (*title*) Continuity girl. **1944** R. MANVELL *Film* I. vi. 68 The director is the admitted co-ordinator of the actors' work, with the continuity girl killing the details. **1970** *Daily Tel.* (Colour Suppl.) 3 July 23 The world of folding chairs, megaphones and continuity girls is put firmly behind him when he turns to domestic film-making. **1941** *B.B.C. Gloss. Broadc. Terms* 7 **Continuity studio*, small studio from which an announcer, supervising the running of a sequence of programmes, makes opening and closing announcements and interpolates interlude material when required. **1957** *B.B.C. Handbk.* 52 The machines are started and stopped by remote control..from a *continuity suite in the case of reproductions. **1962** A. NISBETT *Technique of Sound Studio* 246 *Continuity suite*, a centre through which programmes are routed or where they are reproduced to build a particular service ready for feeding to a transmitter. **1953** K. REISZ *Film Editing* 279 **Continuity title*, title designed to bridge a break in the pictorial continuity. **1921** *Moving Pict. Stories* 9 Dec. 28/2 He knows that the *continuity writer is going to make certain changes. **1928** *Sunday Express* 18 Mar. 4/3 The necessity for such titles as 'Time went on, and brought changes in the circus' would bring most continuity writers into disgrace.

continuo (kənˈtɪn(j)uːəʊ). *Mus.* = BASSO *continuo*; also, an instrument or instruments playing this.

1724 *Short Explic. For. Words Mus. Bks.* 24 *Continuo*, for this see the Words *basso continuo*. **1740** GRASSINEAU tr. *S. de Brossard's Mus. Dict.* 44 *Continuo*, signifies the thorough Bass, as *Basso continuo* is the continual or thorough Bass. **1879** GROVE *Dict. Mus.* I. 151/2 In the score of the 'Matthäus Passion' of Bach..in the recitative a single line and figures is given for the 'continuo' alone. **1942** E. BLOM *Music in Eng.* iii. 41 These harmonic instruments..., it is true, began casually to take on the function they or their descendants assumed quite regularly in the next two centuries under the name of *continuo*.

continuous (kənˈtɪnjuːəs), *a.* [f. L. *continu-us* hanging together, uninterrupted (f. *contin-ēre* in intr. sense 'to hang together,' etc.) + -OUS.]

1. a. Characterized by continuity; extending in space without interruption of substance; having no interstices or breaks; having its parts in immediate connexion; connected, unbroken.

1673 GREW *Anat. Plants* II. iii. §3 It is Compounded of two Bodies. The one Parenchymous; Continuous throughout; yet somewhat Pliable without a solution of its Continuity. **1704** NEWTON *Optics* II. II. (1782) IV. 148 The dark intervals must be diminished, until the neighbouring rings become continuous, and are blended. **1795** SOUTHEY *Joan of Arc* VII. 6 Round the city stretch'd Their line continuous, massy as the wall Erst by the fearful Roman.. raised. **1859** DARWIN *Orig. Spec.* xii. (1873) 320 In most cases the area inhabited by a species is continuous. **1879** LOCKYER *Elem. Astron.* vi. 228 If we light a match and observe its spectrum, we find that it is continuous—that is, from red through the whole gamut of colour to the visible limit of the violet. **1881** MAXWELL *Electr. & Magn.* I. 6 Without describing a continuous line in space.

b. In unbroken connexion *with*; joined continuously *to*; forming one mass *with*.

1692 RAY *Dissol. World* XI. v. (1732) 207 Anciently continuous with Malacca. **1700** S. PARKER *Six Philos. Ess.* 95 The Superficies whereto it was continuous, etc. **1879** HARLAN *Eyesight* ii. 25 The mucous membrane of the eye is continuous with the skin.

†**c.** *fig. Obs.*

1642 FULLER *Holy & Prof. St.* IV. iii. 252 They were so contiguous and near in kinred, they might not be made continuous (one flesh) in marriage.

2. a. Of immaterial things, actions, etc.: Uninterrupted in time, sequence, or essence; going on without interruption; connected, unbroken.

1751 HARRIS *Hermes* II. (1841) 187 Continuatives.. consolidate sentences into one continuous whole. **1832** *Nat. Philos., Electro-Magnet.* xi. §176. 60 (Useful Knowl. Soc.) The currents transmitted by perfect conductors are continuous; that is, their intensity is either constant, or varies insensibly during two consecutive instants. **1867** SMYTH *Sailor's Word-bk.*, *Continuous service men*, those seamen who, having entered for a period, on being paid off, are permitted to have leave, and return to the flag-ship at the port for general service. **1867** FREEMAN *Norm. Conq.* I. App. (1876) 700 A continuous siege of six months. **1875** JOWETT *Plato* (ed. 2) V. 131 The power of abstract study or continuous thought is very rare. **1878** TAIT & STEWART *Unseen Univ.* VII. §215 Which will explain the continuous life of the universe as well as its continuous energy.

b. *Gram.* Of verb tense-forms or aspect: denoting continuous action (see quots.). Cf. EXPANDED *ppl. a.* 2 b and PROGRESSIVE *a.* 3 h.

1887 *N.E.D.* s.v. *be* v., B 15 With the present participle, forming continuous varieties of the tenses. **1892** H. SWEET *New Eng. Gram.* I. 102 Long tenses may be either *continuous* or *recurrent*, denoting repetition, habit, etc. Thus we have a continuous present in *he lives in the country*, a recurrent present in *he goes to Germany twice a year*. **1898** J. C. NESFIELD *Eng. Gram.* v. 58 Continuous [tense]..denotes that the event (in Present, Past, or Future time) is still *continuing*, and is not yet completed; as, 'I am loving', 'I was loving', 'I shall be loving'. **1904** C. T. ONIONS *Advanced Eng. Syntax* 112 When a Continuous Tense refers to a period of action, it often implies habit, e.g. 'I *shall be dining alone* all week'. **1947** W. S. ALLEN *Living Eng. Struct.* 79 It might..be shown that as a continuous tense describes an action as it is taking place, the Present Continuous is the only real present tense we have in English. **1965** F. R. PALMER *Linguistic Study Eng. Verb* iv. 59 Every second pair in the paradigm..is progressive. There is no obvious name for the category... The terms 'continuous' and 'non-continuous' are sometimes used. **1985** R. QUIRK et al. *Comprehensive Gram. Eng. Lang.* 197 The *progressive aspect* (sometimes called the *durative* or *continuous* aspect) indicates a happening *in progress*.

3. *technically.* ***continuous assessment*** (Educ.), the evaluation of a pupil's progress throughout the course of study, based on course-work as well as, or instead of, examinations; see also ASSESSMENT 5 b; ***continuous brake***, a continuous series of carriage brakes controlled from one point, acting upon every carriage or wheel in a train; ***continuous consonants***, those which are capable of prolonged enunciation (opposed to *explosive*); ***continuous creation***, creation viewed as being a continuous process and not a single act at a particular time; *spec.* the view that the universe is in a steady state, new systems being formed continually to replace those that disappear; ***continuous-flow***, used *attrib.* designating a system, device, etc., in which a fluid or other material flows continuously; ***continuous function*** (Math.), a function that varies continuously, and whose differential coefficient therefore never becomes infinite; ***continuous impost***: see IMPOST; ***continuous kiln*** (see quot. 1910); ***continuous miner*** (see quot. 1967); ***continuous process***, an industrial process which operates without interruption (opp. *batch process*); ***continuous spectrum***, 'a spectrum not broken by bands or lines, but having the colors shaded into each other continuously, as that from an incandescent solid or liquid, or a gas under high pressure' (WEBSTER 1890) (cf. quot.

1879 for sense 1 a above); ***continuous stationery*** (see quot. 1942); ***continuous stem*** (Bot.), one without articulations; ***continuous style***, in Gothic Architecture, a style in which the mullions of a window are continued in the tracery, as distinguished from the geometrical style of earlier Gothic; ***continuous tone*** (see quot. 1968); ***continuous variation***, in *Biol.* (see quot. 1961); ***continuous voyage***, a voyage which, though interrupted by stops at ports or otherwise, is regarded as a single voyage in reference to the purpose for which it was undertaken (e.g. the consignment of goods or materials); ***continuous wave***, an electromagnetic (esp. radio) wave having constant amplitude and intensity; also *attrib.*

1959 *15 to 18: Rep. Cent. Advisory Council for Educ. (Eng.)* (Ministry of Educ.) I. xxv. 281 Some Institutes of perfection; the live eyes were a continuous creation.] **1941** C. SINGER *Short Hist. Sci.* v. 140 Averroes believed, not in a single act of creation, but in a *continuous creation. **1950** F. HOYLE *Nature of Universe* v. 107 With continuous creation the apparent contradiction between the expansion of the Universe and the requirement that the background material shall..condense into galaxies is completely overcome. **1956** *Ann. Reg. 1955* 397 The distribution of radio-stars favoured evolutionary theories of cosmology rather than more recent theories of continuous creation. **1958** *New Biol.* XXV. 93 The oxidation tanks were run on the *continuous-flow principle, with recirculation of a portion of the effluent to inoculate the influent. **1965** *Gloss. Aeronaut. Terms (B.S.I.)* §17 p. 3 *Continuous flow oxygen system*, an oxygen system in which the oxygen flows during both inspiration and expiration. **1890** *Sci. Amer.* 11 Jan. 21/3 *(heading)* A *continuous brick kiln. **1901** *Notes on Building Construction* (ed. 5) III. iii. 193 Tunnel kilns, called also Continuous, 'Running', 'Perpetual', or 'Draw-Kilns'. **1910** *Encycl. Brit.* IV. 520/1 Brick-kilns..can all be grouped under two main types—Intermittent kilns and Continuous kilns. *Ibid.* 520/2 The 'continuous' kiln..is really made up of a number of separate kilns or firing-chambers, built in series and connected..in such a manner that the products of combustion from one kiln may be made to pass through a number of other kilns before entering the flue. **1958** A. NELSON *Methods of Working* v. 61 Further studies by mining engineers..led to the design and development of machines which combined the operations of cutting, breaking and loading the coal... These combined machines are popularly known as '*continuous miners'. **1967** *Gloss. Mining Terms (B.S.I.)* VIII. 9 *Continuous miner*, a machine used mainly for the cutting and loading of coal or other mineral in mine entries or narrow places. **1909** *Daily Chron.* 11 June 7/2 Everything being on the automatic and *continuous-process principle. **1922** *Encycl. Brit.* XXXI. 389/1 The case which appears to have presented most difficulty in national legislation is the *continuous process*. **1954** [see BATCH *sb.*[1] 7]. **1961** *Times* 22 Nov. 21/6 Many chemical plants, especially the continuous-process type, need very precise adjustment. **1902** *Encycl. Brit.* XXXII. 124/2 Fluorescent radiation, showing a *continuous or banded spectrum, can be excited in many gases and vapours. **1942** H. A. MADDOX *Dict. Stationery* (ed. 2) 26 **Continuous Stationery*, a modern form of mechanical accounting stationery in which the sheets are of continuous length, sometimes folded concertina fashion. **1959** *B.S.I. News* Dec. 15 The sizes do not necessarily apply to continuous stationery. **1970** *Brit. Printer* June 76 Continuous stationery for computers is one of the fastest-growing specialisations in printing. [**1866** *Treas. Bot.* 325 A stem is said to be continuous which has no joints.] **1849** FREEMAN *Archit.* 379 There is also a tendency..throughout the *Continuous style, to extend the ornamental stonework. **1933** C. W. GAMBLE *Mod. Illustration Processes* vii. 125 We may take..an artist's drawing of a landscape of washes of black pigment upon white paper..as representing a drawing in '*continuous' tone. **1967** E. CHAMBERS *Photolitho-offset* iv. 43 With the indirect method the first negatives are made as formerly and they may be in continuous-tone or in dot formation. **1968** *Gloss. Terms Offset Lithogr. Printing (B.S.I.)* 10 *Continuous tone*, an image in which tonal gradation is produced by changes in density. **1894** W. BATESON *Study of Variation* 18 The fact that *Continuous Variations exist is also none the less a fact. **1961** WEBSTER, *Continuous variation*, variation in which a series of intermediate types connects the extremes. **1806** C. ROBINSON *Rep. Cases Crt. Admir.* V. 365 *marg.*, *Continuous voyage in the colonial trade of the enemy. **1808** *Ibid.* VI. App. note ii, That branch of the colonial principle which relates to continuous voyages. **1902** *Encycl. Brit.* XXXI. 130/2 If the ultimate destination of goods, though shipped first to a neutral port, is enemy's territory, then, according to the 'doctrine of continuous voyages', the goods may be treated as if they had been shipped to the enemy's territory direct. **1911** A. B. SMITH *Mod. Amer. Telephony* xxv. 663 If it were possible to produce *continuous waves for wireless telegraphy. **1920** H. M. DOWSETT *Wireless Telegr.* iv. 70 Continuous wave transmitters. *Ibid.* 92 Any other long-distance continuous wave system. **1933** J. H. MORECROFT *Princ. Radio Communication* (ed. 3) vii. 775 Tube *B* acts as oscillator and detector (self-heterodyne) for reception of continuous-wave signals. **1951** [see *automatic direction finder*].

continuously (kən'tɪnjuːəslɪ), *adv.* [f. prec. + -LY[2].] In a continuous manner; uninterruptedly, without break; continually, constantly.

1678 CUDWORTH *Intell. Syst.* 167 (R.) Which..incorporates the newly received nourishment, and joins it continuously with the preexistent parts of flesh and bone. **1826** FOSTER in *Life & Corr.* (1846) II. 94 He spoke continuously for a considerable time. **1875** LYELL *Princ. Geol.* I. II. xxv. 623 These may sometimes mantle continuously round the whole mass. **1879** *Nature* 20 Nov. 58 A body which is changing its speed every..hundredth part of a moment or what we call continuously. **1881** MAXWELL *Electr. & Magn.* I. 6 A quantity is said to vary continuously, if, when it passes from one value to another, it assumes all the intermediate values.

continuousness (kən'tɪnjuːəsnɪs). [f. as prec. + -NESS.] The state or quality of being continuous; continuity.

1803 W. TAYLOR in *Monthly Mag.* XVI. 224 These two narratives are drawn up with that continuousness, that artless wondering honesty..which might be expected. **1851-9** DARWIN in *Adm. Man. Sci. Enq.* 281 The ... passing into each other. ***space-time continuum***, see SPACE-TIME. Also *attrib.*, as ***continuum mechanics, theory***; **continuum hypothesis** *Math.*, the hypothesis that there is no transfinite cardinal between the cardinal of the set of positive integers and that of the set of real numbers.

1650 SIR T. BROWNE *Pseud. Ep.* II. i. (ed. 2) 40 The fusible salt draws the earth and infusible part into one continuum. **1677** HALE *Prim. Orig. Man.* IV. iv. 327 The admirable accommodation of the several Parts of the Humane Body to make up one Continuum. **1865** GROTE *Plato* I. i. 13 There could be no continuum: each numerical unit was distinct and separated from the rest by a portion of vacant space. *a* **1878** LEWES *Study Psychol.* (1879) 133 To these animals [the wolf and dog] the external world seems a continuum of scents, as to man it is a continuum of sights. **1886** J. WARD in *Encycl. Brit.* XX. 51/1 *(Psychology)* All possible sensations of colour, of tone, and of temperature constitute as many groups of qualitative continua. **1903** B. RUSSELL *Princ. Math.* I. xxxvi. 297 Cantor proves that any series *M* satisfying the above conditions is ordinally similar to the number-continuum, *i.e.* the real numbers from 0 to 1, both inclusive. **1905** *Westm. Gaz.* 14 Aug. 2/1 We must know more of the properties of the ponderable atoms moving in the continuum which fills all space. **1924** W. B. SELBIE *Psychol. of Relig.* iv. 91 There are no doubt good physiological reasons for these phenomena of the sensory continuum. **1938** *Proc. Nat. Acad. Sci.* XXIV. 101 The continuum hypothesis of Georg Cantor. **1951** C. TRUESDELL in *Jrnl. Math. Pures et Appliquées* XXX. 116 The notion of an isotropic function..has been much employed in continuum mechanics. *Ibid.* 150 Continuum theory, being independent of any sort of deterministic mechanics of the ultimate particle, serves as a general guide with which any molecular model must be consistent. **1953** A. E. SMAILES *Geogr. Towns* 33 There is no longer either socially or physically a simple clear-cut dichotomy of town and country; rather it is an urban-rural continuum. **1953** A. A. FRAENKEL *Abstract Set Theory* ii. 152 The assumption that, for every transfinite *t*, 2^t is the cardinal next larger than *t*, is called the generalized continuum hypothesis. **1955** W. NOLL in *Jrnl. Rational Mech. & Anal.* IV. 12 *(heading)* Basic concepts of continuum mechanics. **1962** L. J. COHEN *Diversity of Meaning* (1966) i. 12 Descriptive studies are also needed to abstract and record the pivotal stages in a continuum of change. **1964** *Proc. Nat. Acad. Sci.* LI. 109 Since our additional axiom is quite readily acceptable to most mathematicians..one can regard the unprovability of the Continuum Hypothesis as firmly established.

contir-, obs. f. COUNTER-, e.g. in *contirmont*.

'cont-line. [Of uncertain derivation: it has been suggested that *cont* is a variant of CANT *sb.*[1]]

1. 'The spiral intervals formed between the strands of a rope, by their being twisted together'.

1848 G. BIDDLECOMBE *Art of Rigging* 10. **1874** KNIGHT *Dict. Mech.* 612 *Cont-line*..in *worming*..is filled up with spun yarn or small rope, which brings the rope so treated to a nearly cylindrical shape.

2. 'The space between the bilges of two casks stowed side by side'.

1867 SMYTH *Sailor's Word-bk.*

conto ('kɒntəʊ). In 6–7 counto. [Pg. *conto* = It. *conto*, OF. *cunte*, F. *compte*:—L. *computus*: see COUNT *sb.*] In Portuguese, a million; hence, short for a million reis, worth in Portuguese currency about £220, in Brazilian a little more than half that amount.

1601 HAKLUYT tr. *Galvano's Discov. World* (1862) 14 He neuer..left off to raise and to augment the yerely rent vnto a counto. **1858** SIMMONDS *Dict. Trade Prod.*, A Portuguese word for million; a conto of reis (1000 milreis) is usually expressed thus 1000$000. **1889** *Times* (weekly ed.) 13 Dec. 15/1 The sum of 5,000 contos (£550,000). **1890** *Daily News* 25 Jan. 5/5 The money being subscribed in Brazil. The capital is stated to be 200,000 contos of reis, or over 20 millions sterling. **1891** *Scot. Leader* 13 May 6 (Lisbon) 1200 contos of reis of new silver money coined in virtue of last Friday's decree.

contoid ('kɒntɔɪd), *a.* and *sb.* *Linguistics.* [f. *cont.*, shortening of CONSONANT *sb.* + -OID.] **A.** *adj.* Consonant-like; of consonantal character; *esp.* as contrasted with VOCOID *a.* **B.** *sb.* A speech sound of the consonantal type.

1943 K. L. PIKE *Phonetics* v. 78 Vocoid and contoid groups are strictly delineated by the articulatory and acoustic nature of sounds. *Ibid.* vii. 143 Contoids include stops, fricative nasals, lateral resonant orals, and central fricative orals. **1957** H. J. ULDALL in Hjelmslev & Uldall *Outl. Glossematics* 49 It is possible to regard long vocoids and contoids as manifestations of chains of identical vowels or consonants. **1958** C. F. HOCKETT *Course Mod. Ling.* vii. 67 A contoid..is a sound involving clearly audible turbulence of the airstream at one point or another in the vocal tract, or else a complete interruption of the air stream. Use of the terms 'vocoid' and 'contoid' enables us to reserve the terms 'vowel' and 'consonant' as labels for structurally defined classes of phonemes in specific languages. *Ibid.*, Consonant-like or contoid effects.

... *Rom. Hist.* 25 Medals Contorniate, tho of a bad Master, are rare. **1855** HOPKINS & RIMBAULT *Organ* (1877) 12 A contorniate coin of the Emperor Nero. **1889** S. W. STEVENSON *Dict. Rom. Coins* s.v., Contorniate medals present this peculiarity, that there is scarcely ever any apparent connexion between the obverse and the reverse.

B. *sb.* A medal (or coin) having such a furrowed circumference: applied by modern numismatists to certain brass pieces of Nero and other Roman emperors, the purpose of which is uncertain.

1823-5 T. D. FOSBROKE *Encycl. Antiq.* (1843) 973 Contorniates..are mostly between two and three inches [in] diameter. **1850** LEITCH tr. *Müller's Anc. Art* §207. 198 The contorniati distributed at public games. **1889** S. W. STEVENSON *Dict. Rom. Coins* s.v., All writers appear..to agree in considering that contorniates were not of the nature and value of money..All contorniates are of brass.

con'torniated, con'tourniated, *ppl. a.* = prec. adj.

1727-51 CHAMBERS *Cycl.* s.v., All we have remaining of these contourniated medals, seem to have been struck about the same time. **1730-6** BAILEY (folio), *Contourniated.* **1823** in CRABB.

‖**contorno** (kon'torno). [It. *contorno* circuit, CONTOUR, f. *contornare* to turn together, compass about, put a thing round another (cf. med.L. *contornāre* to round off well), f. L. *con-* + *tornāre* to turn in a lathe, round off, make round, f. *tornus* a turning-lathe.] Contour, outline of a statue or other work of art.

1758 JOHNSON *Idler* No. 76 ⁋3 His mouth full of..the sublimity and grand contorno of Michael Angelo. **1781** MAD. D'ARBLAY *Diary* I. 325 For a background and contorno, who comes up to Mrs. Thrale?

contorsion, obs. form of CONTORTION.

contorsive (kən'tɔːsɪv), *a.* [f. L. *contorsus*, alleged variant of *contortus* (see CONTORT) + -IVE.] Of contorting quality or tendency.

1819 H. BUSK *Vestriad* I. 500 His eye contorsive bent a thousand ways. **1819** —— *Dessert* 711 Or with scored viscera contorsive rue The deleterious trash that vintners brew.

†**con'tort**, *ppl. a. Obs.* [ad. L. *contort-us* pa. pple: see next.] Twisted, contorted.

1570 LEVINS *Manip.* 173 Contort, *contortus*.

contort (kən'tɔːt), *v.* [f. L. *contort-* ppl. stem of *contorquēre*, f. *con-* + *torquēre* to twist.]

1. *trans.* To twist, twist together or round itself; to draw awry; to distort greatly by twisting.

1622 [see CONTORTED]. *c* **1715** CHEYNE (J.), Spires contorted into small spheres. **1756** AMORY *Buncle* (1770) I. 193 These..fleshy fibres are contorted and bound about with..spiral ramifications..of the nerves. **1846** HAWTHORNE *Mosses* I. i. 10 The variety of grotesque shapes into which apple-trees contort themselves. **1852-9** TODD *Cycl. Anat.* IV. 948/1 The cord is thereby contorted into a spiral. **1855** BAIN *Senses & Int.* II. ii. §2 (1864) 121 The features are violently contorted. **1879** LOCKYER *Elem. Astron.* iii. 79 The sedimentary rocks have been..bent, contorted, or twisted to an enormous extent.

fig. **1836-7** SIR W. HAMILTON *Metaph.* (1877) I. xi. 197 Contorted from their established signification. **1864** BOWEN *Logic* vii. 192 Both halves of the reasoning are contorted.

†**2.** To hurl forth as a missile or argument. *Obs.*

c **1562** ABP. PARKER *Def. Priests Marriages* 165 For it may be well verified of you that ye contort to another: He that is once ouer his shoes, forceth not afterward how deepe he wade in the myer.

contorted (kən'tɔːtɪd), *ppl. a.* [f. prec. + -ED.]

1. Twisted, *esp.* twisted together or round itself; drawn awry or out of shape by a twisting action.

Exhibit F

INTERMEDIATE ALGEBRA

EIGHTH EDITION

Margaret L. Lial
American River College

John Hornsby
University of New Orleans

ADDISON-WESLEY
An Imprint of Addison Wesley Longman, Inc.

Reading, Massachusetts • Menlo Park, California • New York • Harlow, England
Don Mills, Ontario • Sydney • Mexico City • Madrid • Amsterdam

Publisher: Jason Jordan

Acquisitions Editor: Jennifer Crum

Project Manager: Kari Heen

Developmental Editor: Terry McGinnis

Managing Editor: Ron Hampton

Production Supervisor: Kathleen A. Manley

Production Services: Elm Street Publishing Services, Inc.

Compositor: Typo-Graphics

Art Editor: Jennifer Bagdigian

Art Development: Meredith Nightingale

Artists: Precision Graphics, Darwen and Vally Hennings, Gary Torrisi, and Bob Giuliani

Marketing Manager: Craig Bleyer

Prepress Buyer: Caroline Fell

Manufacturing Coordinator: Evelyn Beaton

Text and Cover Designer: Susan Carsten

Cover Illustration: © Peter Siu/SIS

Library of Congress Cataloging-in-Publication Data
Lial, Margaret L.
Intermediate algebra.—8th ed. / Margaret L. Lial, John Hornsby.
p. cm.
Includes index.
ISBN 0-321-03646-8 (student ed.)
ISBN 0-321-04132-1 (annot. inst. ed.)
1. Algebra. I. Hornsby, John. II. Title.

QA152.2.L52 2000
512.9—dc21 99-24945
CIP

Printed in the U.S.A.

23456789-VH-02 01 00 99

OBJECTIVE Find the arithmetic mean (average) of a group of numbers. The **arithmetic mean,** or **average,** of a group of numbers is defined as the sum of all the numbers divided by the number of numbers.

Arithmetic Mean or Average

The arithmetic mean, or average, of a group of numbers is symbolized $\bar{x}$ and is found by dividing the sum of the numbers by the number of numbers. That is,

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}.$$

Here the values of x_i represent the individual numbers in the group, and n represents the number of numbers.

EXAMPLE 6 Finding the Arithmetic Mean or Average

The following table shows the number of companies listed on the New York Stock Exchange for each year during the period 1990–1996. What was the average number of listings for this seven-year period?

Year	*Number of Listings*
1990	1774
1991	1885
1992	2088
1993	2361
1994	2570
1995	2675
1996	2907

Source: New York Stock Exchange.

Let $x_1 = 1774$, $x_2 = 1885$, and so on. Since there are 7 numbers in the group, $n = 7$. Therefore,

$$\bar{x} = \frac{\sum_{i=1}^{7} x_i}{7}$$

$$= \frac{1774 + 1885 + 2088 + 2361 + 2570 + 2675 + 2907}{7}$$

$$= 2323 \quad \text{(rounded to the nearest unit).}$$

The average number of listings for this seven-year period was 2323.